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Highlights of Sandia's Photovoltaics Program

Sandia National Laboratories

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In this issue, we feature selected presentations at the Performance and Reliability Workshop.

TOPICS THIS QUARTER

WORLD WIDE WEB
http://www.sandia.gov/pv

PERFORMANCE AND RELIABILITY WORKSHOP

In this volume of the Highlights, we summarize selected papers presented by industry and key users at the 1997 Photovoltaic Performance and Reliability Workshop held August 5-6 in Las Cruces, New Mexico. Representing the National Center for Photovoltaics, Sandia National Laboratories and the National Renewable Energy Laboratory co-sponsored this annual workshop, and the Southwest Research Development Institute based in Las Cruces hosted the event, which drew nearly 100 participants from across the United States. Industry, universities, national laboratories, and government agencies were well represented. Where there was discussion, we also summarize its content. We wrote the summaries based on oral presentations in Las Cruces coupled with the author's written paper if one was submitted for the workshop handbook.

Steve Hester, UPVG.

Are System Issues Being Addressed?

(Reported from oral presentation.)

Hester said that the price of a photovoltaic system is equated with its value. Because of this, all parts of a system must form a workable, affordable infrastructure, including the modules, inverter, tracking structure, batteries, and interconnection with the utility. Improvements in price, performance, and reliability have been achieved for separate elements, he said, but not for whole systems. For example, we have seen significant improvements in modules in the last five to eight years as a direct result of standards, but performance is still lower than expected, and that means the system performance is also lower. In addition, the market for inverters is increasing, there are more manufacturers, anti-islanding techniques have improved, and prices have come down. However, he said that reliability of inverters is still low, and this is the major problem in all photovoltaic systems; such a situation is unacceptable.

Charge controllers have improved in the last few years, Hester said, but we need standards and criteria by which consumers can judge these components. Fixed trackers and tracking structures, both active and passive, are still prone to failure, although several acceptable units have been developed from the standpoint of design and cost. Not much evolution has occurred in the last ten years with respect to batteries and generators; generators tend to be custom built and are hard to integrate into a system. In addition, Hester said there are still too many rules and no commonality in regulations pertaining to interconnection with utilities. These issues and sales, service, repair, maintenance contracts, and training all need to be integrated to form a workable, affordable infrastructure in which photovoltaic systems are sold and operate.

Sandia's on-going reliability study is showing how reliability and cost are interdependent, Hester said. We need accurate and informed

A field team evaluates a small photovoltaic/hybrid system at Arches National Monument in Utah. More than a dozen hybrid systems, such as this one, feed information into Sandia's Photovoltaic Systems Assistance Center database.

information on small, large, grid-connected, and stand-alone systems. We need an increase in reliability and reduction in cost, and we can get closer by using good systems engineering, by installing systems safely, by increasing their reliability and having accurate ratings of systems.

Discussion:

Questioned about why an accurate system rating is crucial, Hester answered that most systems are performing 15 to 20% lower than rated, and this impacts the perceived value of the system. He said this has been true for 10 to 12 years. He said industry needs to be convinced they must demonstrate the reliability of a system, and this is not done now. They should be able to show that they meet UPVG standards. He said that consumers are given top ratings, and the performance of their system is less than the rating; so Hester calls for a way to reliably test and give reliable ratings to whole systems, not just components. ♦

Chuck Whitaker, Endecon Engineering. ***PVUSA Project Team. Lessons Learned from Field Testing: Why We Need System Certification.***

[Condensed from written report.]

In 15 years or so of testing various types of photovoltaic systems in the field, most of the problems we have seen reflect a lack of understanding, testing, or experience, and also reflect a young industry struggling to develop new technologies while providing a low-cost product. Our field experience also suggests that definite progress has been made. Advancements in technology, codes and standards, and industry practice are resulting in better and more reliable components and systems. Changes continue to be made to the National Electrical Code to address deficiencies and confusing issues.

The newest module qualification test standards and safety standards (UL) will lead to improvements in the quality and reliability of components. Most important, however, is the need to implement accreditation and certification procedures to help ensure these tests are performed properly and consistently. It would help all sides of system manufacturing—inspectors, customers, and designers. To date, performance certification is only available on modules; thus, there is no standard way to verify design procedures, installation procedure, performance of the power conditioning unit, or system rating. Nor is there a way to certify an entire system, and this is needed.

A complete system certification would take all these issues into account, and would address system sizing, component selection, safety and performance of components and the like. It might also address operation and maintenance issues. A great deal of activity is being directed toward the development of tests and standards for system certification programs both at home and abroad. It is important the entire photovoltaic community be aware of and involved in the activities to ensure they address the known problems and do not create new ones.

The down side to certification of systems is cost. Certification would tend to stifle innovation and custom designs and encourage standard packages. But entities like the World Bank are behind it because of reliability issues; they need assurances the systems will work as promised.

Top Ten Issues From Field Testing

1. *System output is always less than expected (sometimes greater than bid, but usually because additional modules were added).*
2. *Using Alpha and Beta power conditioning unit hardware and software.*
3. *Using Alpha and Beta tracker controller hardware and software.*
4. *Extensively shaded residential rooftop systems (also bird droppings, chimneys, vents, power poles, etc.) cause problems.*
5. *Improperly wired arrays.*
6. *Use of unlisted equipment even though listed equipment was available.*
7. *Improperly specified components.*
8. *Modules damaged in manufacture, shipping, or installation.*
9. *Mistaken assumption that photovoltaic systems require no maintenance.*
10. *Less than 600 V = 700 V (or 800 or 900); ratings versus failures in testing.*

Courtesy PVUSA

Discussion:

Members of the audience commented that batteries are an issue too, and they are not on the list, nor is safety, which is a top issue, but the workshop moderators said that performance and reliability are the focus at the workshop, and the list is aimed at those issues.

The comment was made that energy management is the issue with batteries—how they are treated and used in the system, because batteries are a mature technology and photovoltaic systems are in adolescence compared with them. “Battery problems” really are because of not understanding batteries. Reference was made to PVGAP and the information available on its Internet site as a possible source of assistance in this area.

Related to the White House Million Roofs Initiative, comment was made that design specifications need to be standardized by consensus between industry and government to ensure the success of the initiative.

The concern here was that poorly designed systems might be installed as part of the initiative and solar would suffer because the project will be so visible. The problem is how to coordinate the consensus and communicate it; in the past, much of the information is simply diffused in many places. Whittaker suggested setting appropriate requirements for systems as a first step. ♦

Mike Stern, Utility Power Group.

Simplicity: What are the Real Concerns for Large Grid-Tied Photovoltaic Systems?

(Reported from oral presentation.)

Stern helped design utility-tied systems at San Luis Obisbo, PVUSA, and Yuma, and said his experience was that utilities test systems in the field without a test plan and they often do not perform even the simplest maintenance. System providers, such as his firm, often do maintenance on their own to prevent failures, and the failure analysis is very informal. He said this is a competitive field, and cost issues are very important; that economics drive safety issues—not just with photovoltaic systems, but with cars and other equipment as well. It is not cost-effective if there are too many safety features, and the actual probability of failure figures in here. Stern called for balancing risk against practicality and cost, saying it is not necessary to try to prevent really remote possibilities. He said in large systems, things tend to be fixed rather than prevented, and maintenance is a part of safety. He said that cost is the key, with reliability playing a second place to it.

He said his firm finds tracking is worth it, because the company sells kilowatthours, and that for flat-plate trackers, in the worst case the system becomes fixed. He said batteries are removed from the calculation of system efficiency and the manufacturer's specifications are taken at face value. With inverters, Stern said that manufacturers expect a customer to do at least what their specifications call for, but it is often hard to get manuals to find out what the specs and requirements are. He said sometimes the poor performance attributed to inverters is the system integrator's fault; he may take a chance in using an inverter he does not have much experience with, and cost is the major factor in his choice. Whether an inverter must be idiot proof or not—as for example the World Bank would like—will affect its cost: should such high reliability be required in view of that it does to price?

Stern said most systems now are not designed to save lots of money, and most are demonstrations with the idea of future sales promotion. Also, many of them are custom designs—some Beta and some really at the research and development stage—and so things like manuals, tests, and specifications are not available. Standard designs would enable them to be written and distributed.

System cost is a bigger factor than reliability, Stern said, and lack of statistics on reliability does not prevent him from selling systems. Furthermore, he said, if there are too many restrictions, the system will be too expensive. There are not as many photovoltaic systems as televisions and VCRs in this country, he quipped, and there are problems with TVs and VCRs too. He said utilities tend to get low prices on systems because so many things are already in place—the site, location, and project managers, for example, whereas an industry has to factor in project development and profit. ♦

The first three-phase 30kVA inverter from Trace Technologies was tested at Sandia's Photovoltaic Systems Evaluation Laboratory by Jerry Ginn before its installation at Arizona Public Servcice Company.

Chris Freitas, Trace Engineering.

Problems and Resolutions in the Trace 4048 Series of Power Conditioners.

(Reported from oral presentation.)

Freitas characterized power conditioners as complex, and said that for this series of Trace power conditioners, the hardware, software, and applications were all improved. He said the company has shipped its 10,000th unit, although some of that total went to other countries and these units differed in detail but the core remains the same. The company made this design flexible to be able to do this, he said.

The improvements Freitas listed include for hardware, an improved ac board, which processes power coming in and going out; an increase of battery changing capacity from 30 amps to 60 amps; improved and larger terminal blocks/connections and a better layout for them; and better labeling. Trace added cooling fans, and improved FET boards (the dc processing part of the inverter), and back-up protection.

Trace found that use of the unit can change the way it operates, and the company based its improvements on this kind of information. For example, the company improved access to the chassis, so that everything is done on the wall and it is easier to service it on-site. Trace improved the user-interface, by adding display back lighting, and the system integration power

A flat-roof photovoltaic array during installation, Abilene Christian University, as part of a program by Central and South West Services, Inc. (Dallas,TX).
(Courtesy Ascension Technology)

panels. Trace offers its complete systems hardware for connection of entire systems, thus averting installation problems that often cause failures.

Freitas said the software improvements include 18 different versions of its software—Trace is now up to revision 4. The units are called by the version of the software used, he said. This version was brand new in 1996, and is still being used. The unit has better generator start routines, increased voltage-range resolution, and improved overcurrent protection.

The application improvements Freitas outlined are going to three-phase systems (especially for overseas' use), having true parallel operation so they can go to 33 kVA of power, and ensuring two units can be used together. This will allow Trace to increase its product base, he said. Trace is working more on integration because having a more complex system opens it up to more chances to fail, Freitas said.

He said Trace makes two modern charge controller units, the C12 and C40, and two archaic but still serviceable units which are complex, but inexpensive. ♦

Miles C. Russell, Daniel Greenberg, Joe Bernier, Ascension Technology, Inc.

Frequency of Problems on More Than 100 Grid-Tied Photovoltaic Systems.

(Condensed from written report.)

Before the photovoltaic industry can successfully serve major market growth, improvements in reliability of grid-tied photovoltaic systems must be demonstrated. To assess the current state of system reliability, a comprehensive look at the repair history of existing grid-tied photovoltaic installations has been undertaken, including the approximately 105 utility-interactive photovoltaic systems that are equipped with dataloggers and are being monitored by Ascension Technology at this time. Data goes back 4 years; new systems are added to our monitoring activity regularly.

These systems range in size from 1 to 6 kilowatts and are located throughout the United States. Many of these sites have multiple systems, such as projects Ascension Technology completed for the Environmental Protection Agency, where each installation comprises three separate photovoltaic arrays and inverters. Data from these systems is retrieved each night by a central computer at Ascension Technology's offices in Waltham, Massachusetts. The data are screened, summarized, and archived for further analysis. As of this writing, the reliability analysis is underway, but far from being completed.

Inverters are the main source of problems with grid-tied photovoltaic systems, but are not the only source. Problems requiring attention have also been observed with modules, disconnect switches and Ascension's earliest version of the photovoltaic Source Circuit Protector. These are the categories we are using to summarize failure types. The results presented at the workshop will, we hope, be useful to the industry at large. We view this material as the beginning of what could certainly become a more consuming and on-going analysis activity—an important one.

The results presented at the workshop follow:

Russell said the reliability study was of 126 2- to 6-kilowatt grid-tied systems at 62 sites across the United States, with 62 data acquisition systems, and of 2- to 6-kilowatt inverters. The study lasted from July 1, 1994 to the present. Most are roof-top systems. The computer gets data daily from all the sites, and there is a follow-up call if any questions arise. A log-book is maintained with all the data. The study has become more rigorous in the last six months, he said, and there is a wide range of variables.

One-hundred twenty-six inverters were involved, from Omnion, Trace, and Abacus, representing 2847 inverter months and 237 inverter years, Russell said. The modules were from Siemens, ASE Americas, Solarex, AstroPower, United Solar, and PV International. The events they looked for were failure of the system to put out power, requiring an experienced person to fix it; trouble with modules or arrays, the inverter, the source circuit protector, or the disconnect switches. They did not include snow, soiling, installation error, or vandalism; they were looking for component failures.

The recorded events numbered 190, with 75% being due to inverter problems, 10% from switches, 10% array problems (21 events were recorded, from modules or wiring), 2% were wiring problems. Of the 62 sites, 53 had no module problems or really minuscule ones that did not take out the whole system. Disconnect switches failing accounted for 20 total events and were counted as wiring problems, but these are pretty much a thing of the past. Inverter problems account for 144 total events, but no major cause can be given to explain them. An 8-kilowatt name plate array on a 6-kilowatt inverter seems to work best, but Russell felt they were still learning about this situation. The 144 events occurred over 237.25 inverter years, and 17 sites had no events (with 19 inverters). Russell said he thinks things are getting better although there is no clear trend yet. None of the failures posed a safety risk for personnel. But with the Million Roofs Initiative becoming a reality, improving all the components in a photovoltaic system is a must. ♦

Michael R. Behnke, Trace Technologies Corporation. ***Power Processing Topologies and Control Strategies: Effects on Large-Scale Hybrid Power System Performance and Reliability.***

(Condensed from written report.)

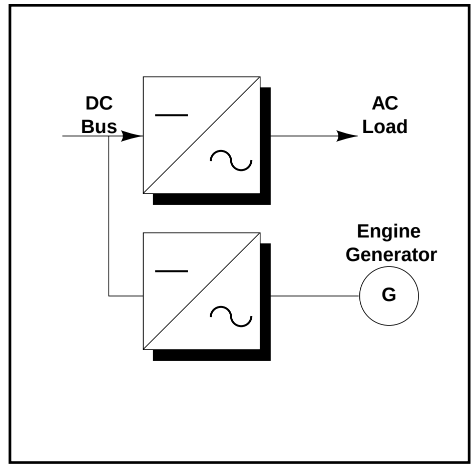
The performance and reliability of large-scale stand-alone hybrid power systems is heavily influenced by the topology of the power electronic subsystem. Commercially available hybrid power processing systems utilize a number of different topologies. The primary differences in these topologies involve the manner in which the ac load is transferred from battery power to generator power, the coupling of the photovoltaic array and battery to the inverter dc bus, and the implementation of the inverter hardware and control software to provide a balanced three-phase voltage source to unbalanced loads. Each of these topologies has its own unique set of benefits and drawbacks in terms of initial cost, reliability and performance.

- AC transfer (or standby UPS) topology vs. in-line UPS topology
- Direct coupling of photovoltaic array and battery to inverter dc bus vs. coupling through active controller(s)
- Twelve-switch vs. six-switch three-phase inverter implementations

The results presented orally at the workshop follow:

Behnke reviewed several common topologies, but stressed that high-reliability, high performance, and low first cost are conflicting requirements; no topology can optimize all three.

From the standpoint of reliability, Behnke said he preferred the in-line uninterruptible power supply topology (sometimes called series topology), in which all the energy passes through the inverter, and the power transfer hardware functions are eliminated. He said this is the only truly seamless transition topology. On the downside, its power losses are greater because all power passes through the inverter. For example, the engine generator output must first be rectified and then inverted to supply ac loads.



This is the preferred in-line uninterrupted power supply topology, the only one that is seamless.

Behnke also discussed parallel topography for hybrid systems, in which ac transfer is handled either by a mechanical or a static switch. Control for mechanical switches is complex, but this is the topology with the lowest loss, he said. The static switch uses simple controls and exhibits low conduction losses. The author emphasized that the inverter/generator transition is crucial. If you can avoid this, problems are lessened, and this is how systems could be specified to avoid problems.

The dc interconnection issues in hybrid systems were also discussed. Behnke presented a comparison of direct coupling of photovoltaics to the battery and coupling through active controllers. He said the direct coupling topology provides lower cost, lower parts count, and lower losses when charging from photovoltaics. The active controller provides decoupled battery and inverter voltages, and may provide peak power tracking. However, he said the losses through the controller are higher, as are parts counts and costs. ♦

The power for lighting an entrance sign at Eleven Mile State Park in Colorado comes from a 100-watt photovoltaic panel.

Chris Dunne, Colorado State Parks and Colorado State Energy Office. ***Design and Maintenance of PV Systems in the Colorado State Parks: Experience With More Than 50 Systems.***

(Reported from oral presentation.)

Dunne said his experience covers issues relating to the design, installation, and maintenance of over 50 small, remote, stand-alone photovoltaic power systems in the Colorado State Parks over the past three years, and he talked about design strategies, component selection, design as it relates to maintenance, installation issues, operational problems, component failure and replacement, and cost of repair and replacement.

Boat ramp lighting at Horseshoe Lake State Park, Colorado. This system features a single 85-watt panel that powers a 36-watt fluorescent light for up to eight hours per night. The system cost about $1500 versus $5000 for an alternative grid-tied solution.

As far as the design of such systems goes, Dunne recommended simplicity, using as few components as possible, being NEC code compliant, sizing components correctly, ensuring ease of replacement/ maintenance, having standard system designs for applications, and using inexpensive and commonly available BOS components.

Dunne's experience with installation led to these recommendations: do as much as possible in a controlled environment, minimize field operations, and in the ideal installation—set the system on the ground (roof) and connect the wire to the load.

Maintenance issues were addressed with these recommendations: perform a semi-annual system check, make replacement of components simple, train local maintenance staff, overcome the fear factor, and clarify ownership issues.

Dunne provided a summary of operation costs. He said he keeps a database on systems and their maintenance records, including the cost and time for all repairs/maintenance. He spent $4,600 in repairs for 50 systems in a year, or about $61 per system per year, which is 5% of the capital cost (it would be 2% without vandalism) on a $1200 system. He said vandalism/theft is a major cause of failure—60% in fact, and this is true nationwide. Dunne said he is aiming toward having a standard design and is writing a specification for a photovoltaic system that companies could bid on to produce. ♦

In an effort to reduce dependence on systems powered by diesel fuel, the U.S. Navy has installed three photovoltaic systems, such as this one, on Santa Cruz Island, California. This 139-kW (dc) system powers a radar station.

The Nottingham home in Rio Linda, CA hosts 3.6 kW of Siemens photovoltaic modules as part of SMUD's pioneer program.

David Collier, Sacramento Utility District.

Maintenance and Reliability of Residential Photovoltaic Systems.

(Reported from oral presentation.)

Since 1992, the Sacramento Utility District has installed and operated 414 utility-owned, grid-connected residential rooftop photovoltaic systems, as shown in the accompanying table.

Collier said that they have not had a great deal of data acquisition from the systems, and that they only meter usage of electricity from photovoltaics. He said in a comparison of systems facing south vs. those facing west, and considering the different types of systems, the west-facing systems gave a little more power, but they suffer in the winter.

As far as maintenance goes, he said they had to service 24% of the systems, but that includes every kind of call. Nuisance trips caused 30% of the calls, and only required a reset. Significant problems accounted for 15%, and they found the inverter was to blame in a significant number of cases. Of the inverter failures, infant mortality of inverters accounted for 70% of the failures, and 30% had repeat problems or problems after the first six months. He said the Trace and Omnion inverters had similar performance records. ♦

Year	Number of systems	System rating	Module	Inverter	Installer
1992	2	2 kW	Kyocera	Pacific 3000	Photocomm
1993	108	2.4-3.6 kW	Siemens	Omnion 2200	Siemens
1994	119	2.4-3.6 kW	Solec	Omnion 22 & 2400	Solec
1995	25	3.6 kW	Solarex	Pacific 4000	RMI
	80	2.7-4.4 kW	Solarex	Trace 5548	Placer
1996	80	2.7-4.4 kW	Solarex	Trace 5548	Placer
1997	50	3 kW	Atlantis	Trace 5548	Atlantis

SMUD: Grid-connected residential rooftop photovoltaic systems installed between 1992 and 1997

BRIEFS

Bureau of Land Management honors Sandians' Work

The Bureau of Land Management presented Hal Post and Mike Thomas of Sandia's Photovoltaic Systems Assistance Center an award in October to recognize their contributions to the Bureau of Land Management in supporting and implementing photovoltaic projects.

The partnership between Sandia and the BLM resulted in 80 successful projects using photovoltaic systems, which are discussed in the collaborative publication "Renew The Public Lands." The BLM said that it was able to realize substantial environmental and economic savings through the projects, and in addition, nearly 3 million visitors a year will be introduced to renewable energy technologies because of the BLM systems.

Please visit Sandia's Web site:

www.sandia.gov/pv

New material has been added, notably the IEEE papers and a paper by David King on photovoltaic module and array performance.

Some of our listings include

- PV components
- Balance of system
- System design
- Projects — lists of projects and success stories
- System operation
- Library: glossary and on-line publications
- Photovoltaics quarterly highlights and announcements
- Answers to frequently asked questions about photovoltaics
- Feedback page — a way to communicate with Sandia's Photovoltaics staff
- A search function

Sandia creates and distributes a variety of publications on photovoltaic systems and their applications. For a list of these documents, please contact the Photovoltaic Systems Assistance Center:

through e-mail: *pvsac@sandia.gov*

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